CLAIMS

We Claim:

1. A catalyst composition comprising at least one metallocene compound and at least one chemically-treated solid oxide, wherein:

a) the metallocene compound has the following formula:

$$(X^1)(X^2)(X^3)(X^4)M^1;$$

wherein M^1 is selected from titanium, zirconium, hafnium, vanadium, niobium, tantalum, chromium, molybdenum, or tungsten;

(X^1) is selected from a Group-I ligand,

wherein the Group-I ligand is selected from a cyclopentadienyl, an indenyl, a fluorenyl, a substituted cyclopentadienyl, a substituted indenyl, or a substituted fluorenyl;

wherein each substituent on the substituted cyclopentadienyl, substituted indenyl, or substituted fluorenyl (X^1) is independently selected from an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, an oxygen group, a sulfur group, a nitrogen group, a phosphorus group, an arsenic group, a carbon group, a silicon group, a germanium group, a tin group, a lead group, a boron group, an aluminum group, an inorganic group, an organometallic group, or a substituted derivative thereof, having from 1 to about 20 carbon atoms; a halide; or hydrogen;

(X^3) is selected from an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, or a substituted derivative thereof, having from 1 to about 20 carbon atoms;

(X^4) is independently selected from a Group-II ligand,

wherein the Group-II ligand is selected from an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, an oxygen group, a sulfur group, a nitrogen group, a phosphorus group, an arsenic group, a carbon group, a silicon group, a germanium group, a tin group, a lead group, a boron group,

an aluminum group, an inorganic group, an organometallic group, or a substituted derivative thereof, having from 1 to about 20 carbon atoms; or a halide;

(X^2) is independently selected from a Group-I or a Group-II ligand;

wherein (X^1) and (X^2) are optionally connected by a bridging group, wherein the length of the bridging group between (X^1) and (X^2) is one, two, or three atoms; the one, two, or one, two, or three atoms of the bridging group are independently selected from C, Si, Ge, or Sn; the bridging group is saturated or unsaturated; and the bridging group is substituted or unsubstituted; and

wherein any substituent on the bridging group is independently selected from an alkenyl group, an alkynyl group, an alkadienyl group, an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, an oxygen group, a sulfur group, a nitrogen group, a phosphorus group, an arsenic group, a carbon group, a silicon group, a germanium group, a tin group, a lead group, a boron group, an aluminum group, an inorganic group, an organometallic group, or a substituted derivative thereof, having from 1 to about 20 carbon atoms; a halide; or hydrogen; and

b) the chemically-treated solid oxide comprises a solid oxide treated with an electron-withdrawing anion;

wherein the solid oxide is selected from silica, alumina, silica-alumina, aluminum phosphate, heteropolytungstates, titania, zirconia, magnesia, boria, zinc oxide, mixed oxides thereof, or mixtures thereof; and

the electron-withdrawing anion is selected from fluoride, chloride, bromide, phosphate, triflate, bisulfate, sulfate, or any combination thereof.

2. The catalyst composition of Claim 1, wherein the chemically-treated solid oxide further comprises a metal or metal ion selected from zinc, nickel, vanadium, silver, copper, gallium, tin, tungsten, molybdenum, or any combination thereof.

3. The catalyst composition of Claim 1, wherein the chemically-treated solid oxide further comprises a metal or metal ion and is selected from zinc-impregnated chlorided alumina, zinc-impregnated fluorided alumina, zinc-impregnated chlorided

silica-alumina, zinc-impregnated fluorided silica-alumina, zinc-impregnated sulfated alumina, or any combination thereof.

4. The catalyst composition of Claim 1, wherein the chemically-treated solid oxide is selected from fluorided alumina, chlorided alumina, bromided alumina, sulfated alumina, fluorided silica-alumina, chlorided silica-alumina, bromided silica-alumina, sulfated silica-alumina, fluorided silica-zirconia, chlorided silica-zirconia, bromided silica-zirconia, sulfated silica-zirconia, or any combination thereof.

5. The catalyst composition of Claim 1, further comprising a cocatalyst selected from an organoaluminum compound, an aluminoxane, an organozinc compound, an organoboron compound, an ionizing ionic compound, a clay material, or any combination thereof.

6. The catalyst composition of Claim 1, further comprising a cocatalyst selected from an organoaluminum compound, wherein the organoaluminum compound has the following formula:

$$Al(X^5)_n(X^6)_{3-n};$$

wherein (X^5) is a hydrocarbyl having from 1 to about 20 carbon atoms; (X^6) is selected from alkoxide or aryloxide having from 1 to about 20 carbon atoms, halide, or hydride; and n is a number from 1 to 3, inclusive.

7. The catalyst composition of Claim 6, wherein the weight ratio of the organoalumium compound to the chemically-treated solid oxide is from about 10:1 to about 1:1,000.

8. The catalyst composition of Claim 6, wherein the organoaluminum compound is selected from trimethylaluminum, triethylaluminum, tripropylaluminum, diethylaluminum ethoxide, tributylaluminum, disobutylaluminum hydride, triisobutylaluminum, or diethylaluminum chloride.

9. The catalyst composition of Claim 1, further comprising a cocatalyst selected from an organozinc compound, wherein the organozinc compound has the following formula:

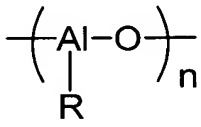
$$Zn(X^5)(X^6);$$

wherein (X^5) is a hydrocarbyl having from 1 to about 20 carbon atoms; (X^6) is selected from a hydrocarbyl, an alkoxide or an aryloxide having from 1 to about 20 carbon atoms, halide, or hydride;

10. The catalyst composition of Claim 1, further comprising a cocatalyst selected from an organozinc compound, wherein the organozinc compound is selected from dimethylzinc, diethylzinc, dipropylzinc, dibutylzinc, dineopentylzinc, di(trimethylsilylmethyl)zinc, or any combination thereof.

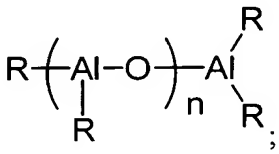
11. The catalyst composition of Claim 1, further comprising a cocatalyst selected from at least one aluminoxane compound, wherein the aluminoxane comprises

a cyclic aluminoxane having the formula:


; wherein

R is a linear or branched alkyl having from 1 to 10 carbon atoms, and n is an integer from 3 to about 10;

a linear aluminoxane having the formula:


; wherein

R is a linear or branched alkyl having from 1 to 10 carbon atoms, and n is an integer from 1 to about 50;

a cage aluminoxane having the formula $R^t_{5m+\alpha}R^b_{m-\alpha}Al_{4m}O_{3m}$, wherein m is 3 or 4 and α is $= n_{Al(3)} - n_{O(2)} + n_{O(4)}$; wherein $n_{Al(3)}$ is the number of three coordinate aluminum atoms, $n_{O(2)}$ is the number of two coordinate oxygen atoms, $n_{O(4)}$ is the number of 4 coordinate oxygen atoms, R^t represents a terminal alkyl group, and R^b

represents a bridging alkyl group; wherein R is a linear or branched alkyl having from 1 to 10 carbon atoms; or

any combination thereof.

12. The catalyst composition of Claim 11, wherein the molar ratio of the aluminum in the aluminoxane to the metallocene in the catalyst composition is from about 1:10 to about 100,000:1.

13. The catalyst composition of Claim 11, wherein the aluminoxane compound is selected from methylaluminoxane, ethylaluminoxane, n-propylaluminoxane, iso-propylaluminoxane, n-butylaluminoxane, t-butylaluminoxane, sec-butylaluminoxane, iso-butylaluminoxane, 1-pentylaluminoxane, 2-pentylaluminoxane, 3-pentylaluminoxane, iso-pentylaluminoxane, neopentylaluminoxane, or a combination thereof.

14. The catalyst composition of Claim 1, further comprising a cocatalyst selected from an organoboron compound, wherein the organoboron compound is selected from tris(pentafluorophenyl)boron, tris[3,5-bis(trifluoromethyl)phenyl]boron, or a combination thereof.

15. The catalyst composition of Claim 14, wherein the molar ratio of the organoboron compound to the metallocene compound in the composition is from about 0.1:1 to about 10:1.

16. The catalyst composition of Claim 1, further comprising a cocatalyst selected from an ionizing ionic compound, wherein the ionizing ionic compound is selected from tri(n-butyl)ammonium tetrakis(p-tolyl)borate, tri(n-butyl)ammonium tetrakis(m-tolyl)borate, tri(n-butyl)ammonium tetrakis(2,4-dimethyl)borate, tri(n-butyl)ammonium tetrakis(3,5-dimethylphenyl)borate, tri(n-butyl)ammonium tetrakis[3,5-bis(trifluoromethyl)phenyl]borate, tri(n-butyl)ammonium tetrakis(pentafluorophenyl)borate, N,N-dimethylanilinium tetrakis(p-tolyl)borate, N,N-dimethylanilinium tetrakis(m-tolyl)borate, N,N-dimethylanilinium tetrakis(2,4-

dimethylphenyl)borate, N,N-dimethylanilinium tetrakis(3,5-dimethylphenyl)borate, N,N-dimethylanilinium tetrakis[3,5-bis(trifluoromethyl)phenyl]borate, N,N-dimethylanilinium tetrakis(pentafluorophenyl)borate, triphenylcarbenium tetrakis(p-tolyl)borate, triphenylcarbenium tetrakis(m-tolyl)borate, triphenylcarbenium tetrakis(2,4-dimethylphenyl)borate, triphenylcarbenium tetrakis(3,5-dimethylphenyl)borate, triphenylcarbenium tetrakis[3,5-bis(trifluoromethyl)phenyl]borate, triphenylcarbenium tetrakis(pentafluorophenyl)borate, tropylium tetrakis(p-tolyl)borate, tropylium tetrakis(m-tolyl)borate, tropylium tetrakis(2,4-dimethylphenyl)borate, tropylium tetrakis(3,5-dimethylphenyl)borate, tropylium tetrakis[3,5-bis(trifluoromethyl)phenyl]borate, tropylium tetrakis(pentafluorophenyl)borate, lithium tetrakis(pentafluorophenyl)borate, lithium tetrakis(phenyl)borate, lithium tetrakis(p-tolyl)borate, lithium tetrakis(m-tolyl)borate, lithium tetrakis(2,4-dimethylphenyl)borate, lithium tetrakis(3,5-dimethylphenyl)borate, lithium tetrafluoroborate, sodium tetrakis(pentafluorophenyl)borate, sodium tetrakis(phenyl) borate, sodium tetrakis(p-tolyl)borate, sodium tetrakis(m-tolyl)borate, sodium tetrakis(2,4-dimethylphenyl)borate, sodium tetrakis(3,5-dimethylphenyl)borate, sodium tetrafluoroborate, potassium tetrakis(pentafluorophenyl)borate, potassium tetrakis(phenyl)borate, potassium tetrakis(p-tolyl)borate, potassium tetrakis(m-tolyl)borate, potassium tetrakis(2,4-dimethylphenyl)borate, potassium tetrakis(3,5-dimethylphenyl)borate, potassium tetrafluoroborate, tri(n-butyl)ammonium tetrakis(p-tolyl)aluminate, tri(n-butyl)ammonium tetrakis(m-tolyl)aluminate, tri(n-butyl)ammonium tetrakis(2,4-dimethyl)aluminate, tri(n-butyl)ammonium tetrakis(3,5-dimethylphenyl)aluminate, tri(n-butyl)ammonium tetrakis(pentafluorophenyl)aluminate, N,N-dimethylanilinium tetrakis(p-tolyl)-aluminate, N,N-dimethylanilinium tetrakis(m-tolyl)aluminate, N,N-dimethylanilinium tetrakis(2,4-dimethylphenyl)aluminate, N,N-dimethylanilinium tetrakis(3,5-dimethylphenyl)aluminate, N,N-dimethylanilinium tetrakis (pentafluorophenyl)aluminate, triphenylcarbenium tetrakis(p-tolyl)aluminate, triphenylcarbenium tetrakis(m-tolyl)-aluminate, triphenylcarbenium tetrakis(2,4-dimethylphenyl)aluminate, triphenylcarbenium tetrakis(3,5-dimethylphenyl)aluminate, triphenylcarbenium tetrakis(pentafluorophenyl)aluminate, tropylium tetrakis(p-tolyl)aluminate, tropylium tetrakis(m-tolyl)aluminate, tropylium tetrakis(2,4-dimethylphenyl)aluminate,

tropylium tetrakis(3,5-dimethylphenyl)aluminate, tropylium tetrakis(pentafluorophenyl)aluminate, lithium tetrakis(pentafluorophenyl)aluminate, lithium tetrakis(phenyl)aluminate, lithium tetrakis(p-tolyl)aluminate, lithium tetrakis(m-tolyl)aluminate, lithium tetrakis(2,4-dimethylphenyl)aluminate, lithium tetrakis(3,5-dimethylphenyl)aluminate, lithium tetrafluoroaluminate, sodium tetrakis(pentafluorophenyl)aluminate, sodium tetrakis(phenyl)aluminate, sodium tetrakis(p-tolyl)aluminate, sodium tetrakis(m-tolyl)aluminate, sodium tetrakis(2,4-dimethylphenyl)aluminate, sodium tetrakis(3,5-dimethylphenyl)aluminate, sodium tetrafluoroaluminate, potassium tetrakis(pentafluorophenyl)aluminate, potassium tetrakis(phenyl)aluminate, potassium tetrakis(p-tolyl)aluminate, potassium tetrakis(m-tolyl)aluminate, potassium tetrakis(2,4-dimethylphenyl)aluminate, potassium tetrakis (3,5-dimethylphenyl)aluminate, potassium tetrafluoroaluminate, or any combination thereof.

17. The catalyst composition of Claim 1, further comprising a cocatalyst selected from a clay material, wherein the clay material is selected from a clay mineral, a natural layered oxide, a synthetic layered oxide, a cogelled clay matrix containing an oxide material, a pillared clay, a zeolite, a natural ion-exchangeable layered mineral, a synthetic ion-exchangeable layered mineral, composites thereof, or combinations thereof.

18. The catalyst composition of Claim 1, wherein the metallocene compound has the following formula:

$$(X^1)(X^2)(X^3)(X^4)M^1;$$

wherein M^1 is selected from titanium, zirconium, hafnium, or vanadium;

(X^1) is selected from a cyclopentadienyl, an indenyl, a fluorenyl, a substituted cyclopentadienyl, a substituted indenyl, or a substituted fluorenyl;

wherein each substituent on the substituted cyclopentadienyl, substituted indenyl, or substituted fluorenyl (X^1) is independently selected from an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, an oxygen group, a sulfur group, a nitrogen group, a phosphorus group, an arsenic group, a carbon group, a silicon group, a germanium group, a tin group, a lead

group, a boron group, an aluminum group, an inorganic group, an organometallic group, or a substituted derivative thereof, having from 1 to about 20 carbon atoms; a halide; or hydrogen; and

(X^2), (X^3), and (X^4) are independently selected from a hydrocarbyl group or a substituted hydrocarbyl group, having from 1 to about 20 carbon atoms

19. The catalyst composition of Claim 1, wherein the metallocene compound has the following formula:

$$(\eta^5\text{-cycloalkadienyl})M^2R^2_nX_{3-n};$$

wherein cycloalkadienyl is selected from cyclopentadienyl, indenyl, fluorenyl, or substituted analogs thereof;

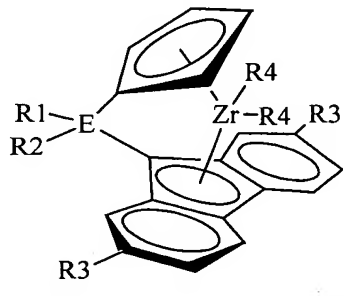
M^2 is selected from Ti, Zr, or Hf;

R^2 is independently selected from substituted or non-substituted alkyl, cycloalkyl, aryl, aralkyl, having from 1 to about 20 carbon atoms;

X is independently selected from F; Cl; Br; I; or substituted or non-substituted alkyl, cycloalkyl, aryl, aralkyl, alkoxide, or aryloxide having from 1 to about 20 carbon atoms; and

n is an integer from 1 to 3 inclusive.

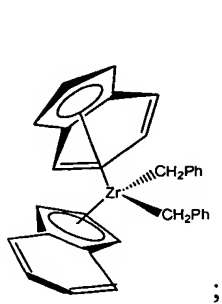
20. The catalyst composition of Claim 1, wherein the metallocene compound is selected from a compound of the formula:



;

wherein E is selected from C, Si, Ge, or Sn; R1 is selected from H or a hydrocarbyl group having from 1 to about 20 carbon atoms; R2 is selected from an alkenyl group having from about 3 to about 12 carbon atoms; and R3 is selected from H or a hydrocarbyl group having from 1 to about 12 carbon atoms; and R4 is selected from H or a hydrocarbyl group having from 1 to about 20 carbon atoms.

21. The catalyst composition of Claim 1, wherein the metallocene compound is selected from:



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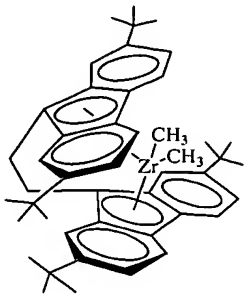

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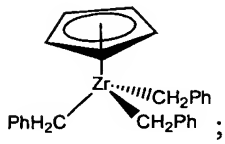

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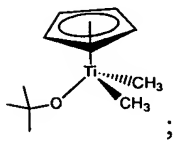

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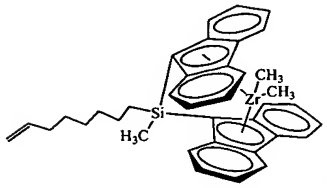

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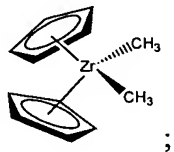

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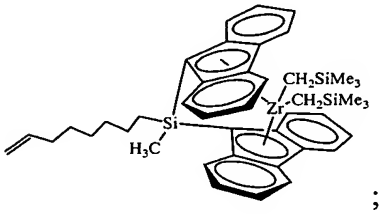


;

or any combination thereof.

22. The catalyst composition of Claim 1, wherein the metallocene compound is selected from:

bis(cyclopentadienyl)hafnium dimethyl;
bis(cyclopentadienyl)zirconium dibenzyl;
1,2-ethanediylbis(η^5-1-indenyl) dimethylhafnium;
1,2-ethanediylbis(η^5-1-indenyl)dimethylzirconium;
3,3-pentanediylbis(η^5-4,5,6,7-tetrahydro-l-indenyl)hafnium dimethyl;
methylphenylsilylbis(η^5-4,5,6,7-tetrahydro-l-indenyl)zirconium dimethyl;
bis(1-*n*-butyl-3-methyl-cyclopentadienyl)zirconium dimethyl;
bis(*n*-butylcyclopentadienyl)zirconium dimethyl;
dimethylsilylbis(1-indenyl)zirconium bis(trimethylsilylmethyl);
octyl(phenyl)silylbis(1-indenyl)hafnium dimethyl;
dimethylsilylbis(η^5-4,5,6,7-tetrahydro-l-indenyl)zirconium dimethyl;
dimethylsilylbis(2-methyl-l-indenyl)zirconium dibenzyl;
1,2-ethanediylbis(9-fluorenyl)zirconium dimethyl;
(indenyl)trisbenzyl titanium(IV);

(isopropylamidodimethylsilyl)cyclopentadienyltitanium dibenzyl;

bis(pentamethylcyclopentadienyl)zirconium dimethyl;

bis(indenyl) zirconium dimethyl;

methyl(octyl)silylbis(9-fluorenyl)zirconium dimethyl;

bis(2,7-di-*tert*-butylfluorenyl)-ethan-1,2-diyl)zirconium(IV) dimethyl;

or any combination thereof.

23. A catalyst composition consisting essentially of at least one metallocene compound and at least one chemically-treated solid oxide, wherein:

a) the metallocene compound has the following formula:

$$(X^1)(X^2)(X^3)(X^4)M^1;$$

wherein M^1 is selected from titanium, zirconium, hafnium, vanadium, niobium, tantalum, chromium, molybdenum, or tungsten;

(X^1) is selected from a Group-I ligand,

wherein the Group-I ligand is selected from a cyclopentadienyl, an indenyl, a fluorenyl, a substituted cyclopentadienyl, a substituted indenyl, or a substituted fluorenyl;

wherein each substituent on the substituted cyclopentadienyl, substituted indenyl, or substituted fluorenyl (X^1) is independently selected from an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, an oxygen group, a sulfur group, a nitrogen group, a phosphorus group, an arsenic group, a carbon group, a silicon group, a germanium group, a tin group, a lead group, a boron group, an aluminum group, an inorganic group, an organometallic group, or a substituted derivative thereof, having from 1 to about 20 carbon atoms; a halide; or hydrogen;

(X^3) is selected from an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, or a substituted derivative thereof, having from 1 to about 20 carbon atoms;

(X^4) is independently selected from a Group-II ligand,

wherein the Group-II ligand is selected from an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, an oxygen group, a sulfur group, a nitrogen group, a phosphorus group, an arsenic group, a carbon

group, a silicon group, a germanium group, a tin group, a lead group, a boron group, an aluminum group, an inorganic group, an organometallic group, or a substituted derivative thereof, having from 1 to about 20 carbon atoms; or a halide;

(X^2) is independently selected from a Group-I or a Group-II ligand;

wherein (X^1) and (X^2) are optionally connected by a bridging group, wherein the length of the bridging group between (X^1) and (X^2) is one, two, or three atoms; the one, two, or one, two, or three atoms of the bridging group are independently selected from C, Si, Ge, or Sn; the bridging group is saturated or unsaturated; and the bridging group is substituted or unsubstituted; and

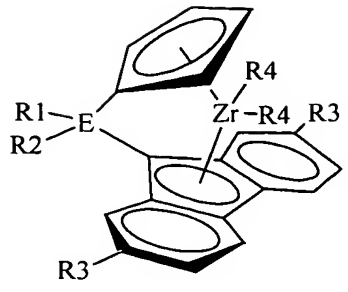
wherein any substituent on the bridging group is independently selected from an alkenyl group, an alkynyl group, an alkadienyl group, an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, an oxygen group, a sulfur group, a nitrogen group, a phosphorus group, an arsenic group, a carbon group, a silicon group, a germanium group, a tin group, a lead group, a boron group, an aluminum group, an inorganic group, an organometallic group, or a substituted derivative thereof, having from 1 to about 20 carbon atoms; a halide; or hydrogen; and

b) the chemically-treated solid oxide comprises a solid oxide treated with an electron-withdrawing anion;

wherein the solid oxide is selected from silica, alumina, silica-alumina, aluminum phosphate, heteropolytungstates, titania, zirconia, magnesia, boria, zinc oxide, mixed oxides thereof, or mixtures thereof; and

the electron-withdrawing anion is selected from fluoride, chloride, bromide, phosphate, triflate, bisulfate, sulfate, or any combination thereof.

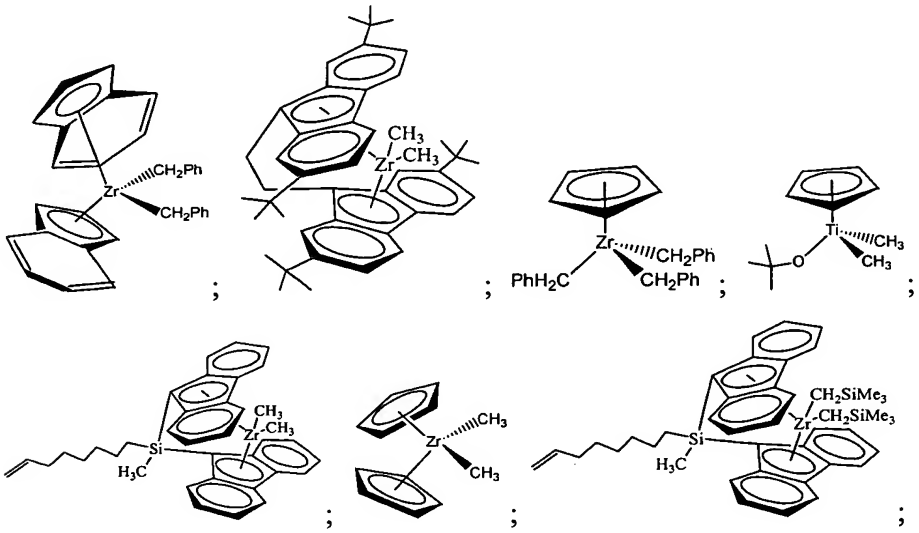
24. The catalyst composition of Claim 23, wherein the metallocene compound is selected from a compound of the formula:



;

wherein E is selected from C, Si, Ge, or Sn; R1 is selected from H or a hydrocarbyl group having from 1 to about 20 carbon atoms; R2 is selected from an alkenyl group having from about 3 to about 12 carbon atoms; and R3 is selected from H or a hydrocarbyl group having from 1 to about 12 carbon atoms; and R4 is selected from H or a hydrocarbyl group having from 1 to about 20 carbon atoms.

25. The catalyst composition of Claim 23, wherein the metallocene compound is selected from:



or any combination thereof.

26. The catalyst composition of Claim 23, wherein the metallocene compound is selected from:

bis(cyclopentadienyl)hafnium dimethyl;

bis(cyclopentadienyl)zirconium dibenzyl;

1,2-ethanediylbis(η^5-1-indenyl) dimethylhafnium;

1,2-ethanediylbis(η^5-1-indenyl)dimethylzirconium;

3,3-pentanediylbis(η^5-4,5,6,7-tetrahydro-l-indenyl)hafnium dimethyl;

methylphenylsilylbis(η^5-4,5,6,7-tetrahydro-l-indenyl)zirconium dimethyl;

bis(1-*n*-butyl-3-methyl-cyclopentadienyl)zirconium dimethyl;

bis(*n*-butylcyclopentadienyl)zirconium dimethyl;

dimethylsilylbis(1-indenyl)zirconium bis(trimethylsilylmethyl);

octyl(phenyl)silylbis(1-indenyl)hafnium dimethyl;

dimethylsilylbis(η^5-4,5,6,7-tetrahydro-l-indenyl)zirconium dimethyl;

dimethylsilylbis(2-methyl-l-indenyl)zirconium dibenzyl;

1,2-ethanediylbis(9-fluorenyl)zirconium dimethyl;

(indenyl)trisbenzyl titanium(IV);

(isopropylamidodimethylsilyl)cyclopentadienyltitanium dibenzyl;

bis(pentamethylcyclopentadienyl)zirconium dimethyl;

bis(indenyl) zirconium dimethyl;

methyl(octyl)silylbis(9-fluorenyl)zirconium dimethyl;

bis(2,7-di-*tert*-butylfluorenyl)-ethan-1,2-diyl)zirconium(IV) dimethyl;

or any combination thereof.

27. A catalyst composition consisting essentially of a metallocene compound and a chemically-treated solid oxide, wherein:

a) the metallocene compound has the following formula:

$$(X^1)(X^2)(X^3)(X^4)M^1;$$

wherein M^1 is selected from titanium, zirconium, hafnium, or vanadium;

(X^1) is selected from a cyclopentadienyl, an indenyl, a fluorenyl, a substituted cyclopentadienyl, a substituted indenyl, or a substituted fluorenyl;

wherein each substituent on the substituted cyclopentadienyl, substituted indenyl, or substituted fluorenyl (X^1) is independently selected from an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, an oxygen group, a sulfur group, a nitrogen group, a phosphorus group, an arsenic group, a carbon group, a silicon group, a germanium group, a tin group, a lead group, a boron group, an aluminum group, an inorganic group, an organometallic

group, or a substituted derivative thereof, having from 1 to about 20 carbon atoms; a halide; or hydrogen; and

(X^2), (X^3), and (X^4) are independently selected from a hydrocarbyl group or a substituted hydrocarbyl group, having from 1 to about 20 carbon atoms; and

b) the chemically-treated solid oxide comprises a solid oxide treated with an electron-withdrawing anion;

wherein the solid oxide is selected from silica, alumina, silica-alumina, aluminum phosphate, heteropolytungstates, titania, zirconia, magnesia, boria, zinc oxide, mixed oxides thereof, or mixtures thereof; and

the electron-withdrawing anion is selected from fluoride, chloride, bromide, phosphate, triflate, bisulfate, sulfate, or any combination thereof.

28. A catalyst composition consisting essentially of a metallocene compound and a chemically-treated solid oxide, wherein:

a) the metallocene compound has the following formula:

$$(\eta^5\text{-cycloalkadienyl})M^2R^2_nX_{3-n};$$

wherein cycloalkadienyl is selected from cyclopentadienyl, indenyl, fluorenyl, or substituted analogs thereof;

M^2 is selected from Ti, Zr, or Hf;

R^2 is independently selected from substituted or non-substituted alkyl, cycloalkyl, aryl, aralkyl, having from 1 to about 20 carbon atoms;

X is independently selected from F; Cl; Br; I; or substituted or non-substituted alkyl, cycloalkyl, aryl, aralkyl, alkoxide, or aryloxide having from 1 to about 20 carbon atoms; and

n is an integer from 1 to 3 inclusive; and

b) the chemically-treated solid oxide comprises a solid oxide treated with an electron-withdrawing anion;

wherein the solid oxide is selected from silica, alumina, silica-alumina, aluminum phosphate, heteropolytungstates, titania, zirconia, magnesia, boria, zinc oxide, mixed oxides thereof, or mixtures thereof; and

the electron-withdrawing anion is selected from fluoride, chloride, bromide, phosphate, triflate, bisulfate, sulfate, or any combination thereof.

29. A composition of matter comprising:

a) a metallocene compound having the following formula:

$$(X^1)(X^2)(X^3)(X^4)M^1;$$

wherein M^1 is selected from titanium, zirconium, hafnium, vanadium, niobium, tantalum, chromium, molybdenum, or tungsten;

(X^1) is selected from a Group-I ligand,

wherein the Group-I ligand is selected from a cyclopentadienyl, an indenyl, a fluorenyl, a substituted cyclopentadienyl, a substituted indenyl, or a substituted fluorenyl;

wherein each substituent on the substituted cyclopentadienyl, substituted indenyl, or substituted fluorenyl (X^1) is independently selected from an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, an oxygen group, a sulfur group, a nitrogen group, a phosphorus group, an arsenic group, a carbon group, a silicon group, a germanium group, a tin group, a lead group, a boron group, an aluminum group, an inorganic group, an organometallic group, or a substituted derivative thereof, having from 1 to about 20 carbon atoms; a halide; or hydrogen;

(X^3) is selected from an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, or a substituted derivative thereof, having from 1 to about 20 carbon atoms;

(X^4) is independently selected from a Group-II ligand,

wherein the Group-II ligand is selected from an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, an oxygen group, a sulfur group, a nitrogen group, a phosphorus group, an arsenic group, a carbon group, a silicon group, a germanium group, a tin group, a lead group, a boron group, an aluminum group, an inorganic group, an organometallic group, or a substituted derivative thereof, having from 1 to about 20 carbon atoms; or a halide;

(X^2) is independently selected from a Group-I or a Group-II ligand;

wherein (X^1) and (X^2) are optionally connected by a bridging group, wherein the length of the bridging group between (X^1) and (X^2) is one, two, or three atoms; the one, two, or one, two, or three atoms of the bridging group are independently selected

from C, Si, Ge, or Sn; the bridging group is saturated or unsaturated; and the bridging group is substituted or unsubstituted; and

wherein any substituent on the bridging group is independently selected from an alkenyl group, an alkynyl group, an alkadienyl group, an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, an oxygen group, a sulfur group, a nitrogen group, a phosphorus group, an arsenic group, a carbon group, a silicon group, a germanium group, a tin group, a lead group, a boron group, an aluminum group, an inorganic group, an organometallic group, or a substituted derivative thereof, having from 1 to about 20 carbon atoms; a halide; or hydrogen; and

b) a chemically-treated solid oxide comprising a solid oxide treated with an electron-withdrawing anion,

wherein the solid oxide is selected from silica, alumina, silica-alumina, aluminum phosphate, heteropolytungstates, titania, zirconia, magnesia, boria, zinc oxide, mixed oxides thereof, or mixtures thereof; and

the electron-withdrawing anion is selected from fluoride, chloride, bromide, phosphate, triflate, bisulfate, sulfate, or combinations thereof.

30. A process to produce a catalyst composition comprising contacting a metallocene compound and a chemically-treated solid oxide, wherein:

a) the metallocene compound has the following formula:

$$(X^1)(X^2)(X^3)(X^4)M^1;$$

wherein M^1 is selected from titanium, zirconium, hafnium, vanadium, niobium, tantalum, chromium, molybdenum, or tungsten;

(X^1) is selected from a Group-I ligand,

wherein the Group-I ligand is selected from a cyclopentadienyl, an indenyl, a fluorenyl, a substituted cyclopentadienyl, a substituted indenyl, or a substituted fluorenyl;

wherein each substituent on the substituted cyclopentadienyl, substituted indenyl, or substituted fluorenyl (X^1) is independently selected from an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, an oxygen group, a sulfur group, a nitrogen group, a phosphorus group, an

arsenic group, a carbon group, a silicon group, a germanium group, a tin group, a lead group, a boron group, an aluminum group, an inorganic group, an organometallic group, or a substituted derivative thereof, having from 1 to about 20 carbon atoms; a halide; or hydrogen;

(X^3) is selected from an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, or a substituted derivative thereof, having from 1 to about 20 carbon atoms;

(X^4) is independently selected from a Group-II ligand,

wherein the Group-II ligand is selected from an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, an oxygen group, a sulfur group, a nitrogen group, a phosphorus group, an arsenic group, a carbon group, a silicon group, a germanium group, a tin group, a lead group, a boron group, an aluminum group, an inorganic group, an organometallic group, or a substituted derivative thereof, having from 1 to about 20 carbon atoms; or a halide;

(X^2) is independently selected from a Group-I or a Group-II ligand;

wherein (X^1) and (X^2) are optionally connected by a bridging group, wherein the length of the bridging group between (X^1) and (X^2) is one, two, or three atoms; the one, two, or one, two, or three atoms of the bridging group are independently selected from C, Si, Ge, or Sn; the bridging group is saturated or unsaturated; and the bridging group is substituted or unsubstituted; and

wherein any substituent on the bridging group is independently selected from an alkenyl group, an alkynyl group, an alkadienyl group, an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, an oxygen group, a sulfur group, a nitrogen group, a phosphorus group, an arsenic group, a carbon group, a silicon group, a germanium group, a tin group, a lead group, a boron group, an aluminum group, an inorganic group, an organometallic group, or a substituted derivative thereof, having from 1 to about 20 carbon atoms; a halide; or hydrogen; and

b) the chemically-treated solid oxide comprises a solid oxide treated with an electron-withdrawing anion;

wherein the solid oxide is selected from silica, alumina, silica-alumina, aluminum phosphate, heteropolytungstates, titania, zirconia, magnesia, boria, zinc oxide, mixed oxides thereof, or mixtures thereof; and

the electron-withdrawing anion is selected from fluoride, chloride, bromide, phosphate, triflate, bisulfate, sulfate, or any combination thereof.

31. A process for polymerizing olefins in the presence of a catalyst composition, comprising contacting the catalyst composition with at least one type of olefin monomer, wherein the catalyst composition consists essentially of:

a) a metallocene compound having the following formula:

$$(X^1)(X^2)(X^3)(X^4)M^1;$$

wherein M^1 is selected from titanium, zirconium, hafnium, vanadium, niobium, tantalum, chromium, molybdenum, or tungsten;

(X^1) is selected from a Group-I ligand,

wherein the Group-I ligand is selected from a cyclopentadienyl, an indenyl, a fluorenyl, a substituted cyclopentadienyl, a substituted indenyl, or a substituted fluorenyl;

wherein each substituent on the substituted cyclopentadienyl, substituted indenyl, or substituted fluorenyl (X^1) is independently selected from an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, an oxygen group, a sulfur group, a nitrogen group, a phosphorus group, an arsenic group, a carbon group, a silicon group, a germanium group, a tin group, a lead group, a boron group, an aluminum group, an inorganic group, an organometallic group, or a substituted derivative thereof, having from 1 to about 20 carbon atoms; a halide; or hydrogen;

(X^3) is selected from an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, or a substituted derivative thereof, having from 1 to about 20 carbon atoms;

(X^4) is independently selected from a Group-II ligand,

wherein the Group-II ligand is selected from an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, an oxygen group, a sulfur group, a nitrogen group, a phosphorus group, an arsenic group, a carbon

group, a silicon group, a germanium group, a tin group, a lead group, a boron group, an aluminum group, an inorganic group, an organometallic group, or a substituted derivative thereof, having from 1 to about 20 carbon atoms; or a halide;

(X^2) is independently selected from a Group-I or a Group-II ligand;

wherein (X^1) and (X^2) are optionally connected by a bridging group, wherein the length of the bridging group between (X^1) and (X^2) is one, two, or three atoms; the one, two, or one, two, or three atoms of the bridging group are independently selected from C, Si, Ge, or Sn; the bridging group is saturated or unsaturated; and the bridging group is substituted or unsubstituted; and

wherein any substituent on the bridging group is independently selected from an alkenyl group, an alkynyl group, an alkadienyl group, an aliphatic group, an aromatic group, a cyclic group, a combination of aliphatic and cyclic groups, an oxygen group, a sulfur group, a nitrogen group, a phosphorus group, an arsenic group, a carbon group, a silicon group, a germanium group, a tin group, a lead group, a boron group, an aluminum group, an inorganic group, an organometallic group, or a substituted derivative thereof, having from 1 to about 20 carbon atoms; a halide; or hydrogen; and

b) a chemically-treated solid oxide comprising a solid oxide treated with an electron-withdrawing anion;

wherein the solid oxide is selected from silica, alumina, silica-alumina, aluminum phosphate, heteropolytungstates, titania, zirconia, magnesia, boria, zinc oxide, mixed oxides thereof, or mixtures thereof; and

the electron-withdrawing anion is selected from fluoride, chloride, bromide, phosphate, triflate, bisulfate, sulfate, or any combination thereof.